Printer Simulation Model

P.L.J. Welten and C.J.H. de Zeeuw
Stork Digital Imaging
Boxmeer, The Netherlands

Abstract

Image quality is one of the most important features of any printer, and unfortunately also one of the least tangible.

In developing a new printer, it would be convenient to have a method to predict what the image quality of this printer will be, before one has actually built it. One method is to try and estimate the image quality parameters (like graininess, line sharpness, bleeding etc) from the design parameters like drop size, placement accuracy, interlacing, ink behavior etc.

However the traditional image quality parameters produce a series of numbers which are not easily interpreted, making it difficult to determine which printer design parameters are too tight or too wide.

Therefore we tried to simulate the output of the printer with different design parameters to get an idea of the print quality of the printer which is understandable for everyone.

To produce this simulation, an image is put through the normal color management, dithering and interlacing scheme, and for each drop of ink, the position of this drop (including all positioning errors), its size and intensity is stored. This information of drop positions and properties is fed to a raster image processor, to create an image at a higher resolution than the printer we try to simulate. This high-resolution image can than be printed on either a high-resolution printer for normal viewing, or enlarged for viewing from a larger distance.

Introduction

In every development, there is a desire to see the result of the development before the development is done. Of course this is impossible, but to give at least an idea of the results, people often use scale models (architecture), mock-up, or for instance simulations.

When building a printer, one of the most important features is its print quality. One can of course judge the printer quality by a set of parameters, but the disadvantage thereof is that these parameters are difficult to interpret for most people.

The development of printers is also complicated by the fact that there are no ‘easy’ specifications, which will guarantee a good result. There are of course some general trends, for example a lower drop volume usually increases image quality, but for instance dot placement inaccuracy both causes graininess (undesired), but also masks effects like small systematic errors in dot placement accuracy.

The model is developed for new development of printers (hardware and dithering software), but in this paper, the model is compared to existing printers, to show possibilities and weaknesses of this simulation.

Simulation Software

The first step of the simulation is identical to normal printing of the image. The image is first color managed (if desired) and dithered. This dithered image represents where how many drops of ink need to be printed.

The dithered image is fed to a software program which has knowledge how the printer and its printhead are built. The program has a software representation of the printhead, which is moved over the (dithered) image in the way the printer would move. Thus, it is possible to calculate for each drop with which nozzle it will be fired and at what time.

The program then calculates the position of each drop (or series of drops), its size and intensity. Since it is known for each drop with which nozzle it is fired, it is possible to take into account missing jets, systematic and random deviations in position and intensity for each jet.

This data is then again fed to another program (a kind of RIP) which turns all these positions into an (enlarged) image. This rip has some basic knowledge of how overlapping ink drops will add up.

The rip can also apply an intensity profile to the dot, since normally dots are more intensely colored in the center, and less intensely colored on the outside.

The resulting image is then printed on a normal printer. Since a simulation contains a lot of drops, it useful to ensure that the program can work quite fast. To improve speed, the program first sorts all the data over the X coordinate. The program also knows the maximum drop size, and reads only enough drops to be able to make a complete line in Y direction. In memory the drops are also sorted in a number of bins.

Typical speed is approximately 15 minutes for a 640*400 pixel image (500000 drops) at an enlargement of 10 times.. Both calculation of drop position and RIP take about fifty percent of the time

Typically we use an enlargement of 10 times, meaning that each pixel in the original image corresponds to 10 pixels in the simulated image. Since the printer we use, has a pixel size of 83 microns, we can simulate positional error up to 8.3 microns.

Units of Measure

All ink amounts are represented in bytes (0-255). Since by itself the printer is linearised in Lab, this means that value 127 is approximately halfway (in Lab coordinates) between 0 and 255.

Sizes and locations are partly measured in microns (the first part of the simulation) and partly in pixels (in the RIP) in the simulated output image.

Addition of Inks

One of the important parameters of the simulation is how different ink drops will add up. The model chosen is a linear addition in density. As a model, the normal printing curve with a solid density of 1.9 and a dot gain of 19% was used to convert the units of measure (0-255) to density's, add them, and then convert them back to units of measure. To achieve high speed in the simulation, a 2 dimensional lookup table was used with 256 columns and rows, which directly gives the added value.

Instrumentation

Printing System:

For all the experiments and simulations, a DuPont Digital Cromalin AX4 printer was used with DP10M (matte) paper. This is a continuous inkjet (Hertz type) printer which can print up to 15 drops (each 5.81 pl) per pixel (304.8 DPI 83 micron pixel size). It is a drum printer with four nozzles (one each for K C M and Y) The distance between the nozzles is 12 mm. This type of printer is normally used for contract proofing.

Color Measurements

The colors were measured with a Gretag Spectrolino 8 mm spectrophotometer. This type has a larger measurement opening than the normal Spectrolino's, thus averaging more (simulated) dots.

Image Measurements:

Measurements on dot size were done with a QEA IAS1000[1] system. This consists of a CCD video camera with optics mounted over an XY-table on which the sample rests. This system handles the calibration of CCD values to reflection values and video camera sizes to actual sizes in microns. It also holds the Gretag Spectrolino 8 mm.

Calibrating the Simulation

In this paper we will use the AX4 printer as example. Since the AX-4 printer will deposit up to 15 drops into one pixel nearly at once, these are not simulated as 15 separate drops, but as one drop with 15 different possible intensities and sizes.

For the system to be useful, it is essential that the results of a simulation are comparable to the real prints. Therefore it is necessary to determine the parameters of the simulation. Very important are of course the size of the drops and the positioning accuracy.

Measuring the size of a drop can be quite difficult, since a drop can spread which means that the intensity of the drop reduces from its middle to the edges. This again implies that the drop size is dependent of the threshold level.

The Dot size was measured at a number of threshold values with the QEA system to determine how much a drop spreads over the paper. The QEA system actually measures the area of the dot. Assuming the dot is circular, this can be converted to a dot diameter. The results are shown in table 1. The ECD is the equivalent circular diameter.

Table 1 Dot diameter (microns) at various threshold levels

Reflection	ECD	ECD	ECD	ECD	ECD	ECD
Drops/pixel	15	15	4	4	1	1
Color	M	K	K	M	K	M
19	36	0	17	0	0	0
27	89	127	61	3	20	0
36	107	140	78	49	35	21
45	121	152	89	70	45	33
54	133	163	99	86	56	45
63	150	178	110	102	72	62
71	183	201	124	129	124	126

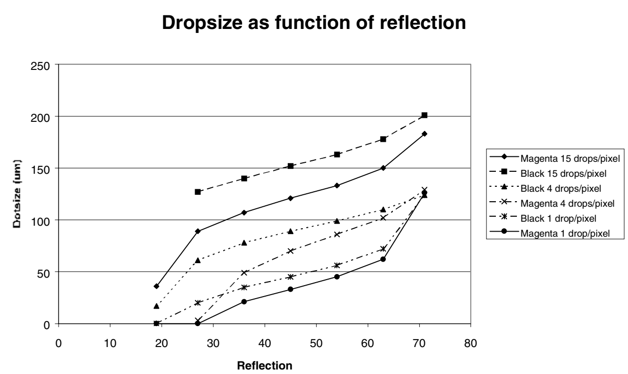

Figure 1 Dot size at various threshold levels

These curves were normalized to one dot size and averaged, resulting in an average drop-diameter/reflection curve, this curve was one input in the model. One other important parameter is the color intensity of the drops. For the maximum amount of ink (15drops/pixel) we used the maximum intensity (255) in the simulation. For the other amounts of drops/pixel we scaled the simulated intensity according to the reflections of the real dots.

Examples Simulation vs Real prints:

Color Effect of Alignment Errors

One of our research tools is a printer in which we can vary the step size of the printhead during printing (normally this is fixed). If combined with the nozzle to nozzle distance, it is possible to cause alignment errors between the colors. This leads to changes in the produced color, especially in the four color gray, since the overlap of black ink and the other inks varies along with the alignment error. Photographs of the simulation, and the real prints are shown in figures 2 and 3.

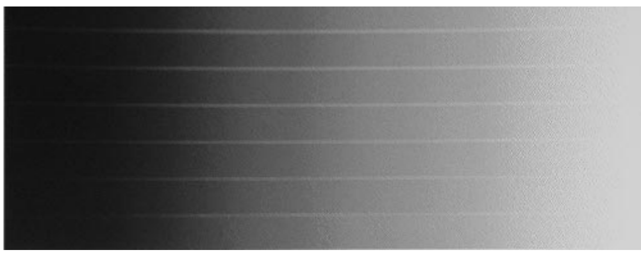

Figure 2. Simulated effect of alignment errors on colors in 4 color grey

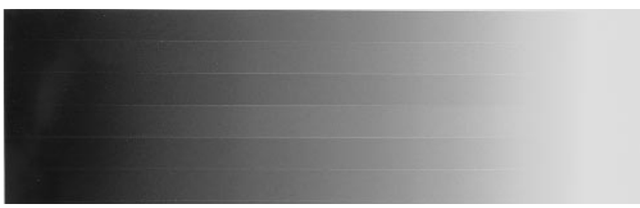

Figure 3 Photograph of real print with color bands due to forced alignment errors

The results show that alignment errors are reasonable well reproduced.

Colormatch

With the above values for intensity and size with no placement errors, a 288 point color book was simulated and printed. Both color books were measured and compared showing and average dE of 5.2 and a maximum of 13

Comparison of Graininess

However if one looks at real prints, and their simulation (figures 3 and 4), it is obvious that the simulated dots are way to sharp, and that the real dots are much more diffuse. It is expected that this is partly due to the effect of optical dot gain which occurs in the real prints. The optical dot gain causes the white of the real print near ink drops to be slightly colored, and the dots of the real print to be slightly less colored.

Figure 4. Scanned real print

Figure 5. Scanned simulated image with no positional errors

To simulate this optical dot gain, an attempt is made to make the influence sphere of the dots much larger (quadruple in size), less intense, and use an intensity profile which causes the drops to be the same size, but with a low intensity at larger distance, see figure 6. The intensity profile beyond the drop edge is proportional with the inverse of the distance from the edge.

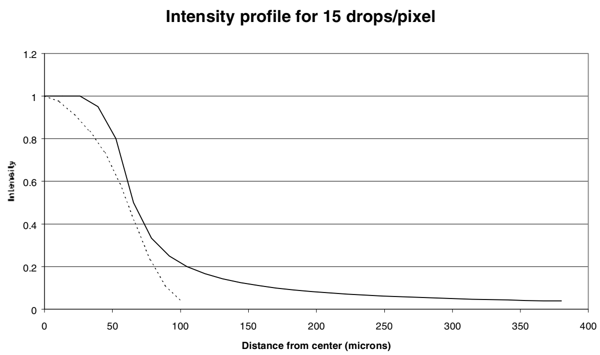

Figure 6. Intensity profile of the dots. The dotted line is the profile used for figures 2-5. The straight line is used for figure 7.

This results in a much larger effect of the drops, without increasing the reproduction curve too much, see figure 7.

The results show that this does reduce the graininess of the image.

Figure 7. Scanned simulation with optical dot gain and errors

Conclusion

The present simulation produces colors that are reasonably accurate when compared to reality. The goal is not to achieve an excellent color match, but to obtain color that is comparable.

The graininess of the simulated print is higher than reality. It is expected that this is partly due to the phenomenon of optical dot gain, This optical dot gain makes the effect of the drops larger than one would expect from their physical size due to light scattering in the paper. Causing a slight coloration of a region surrounding the dot, reducing the contrast between the dot and its surroundings. Some simulations were made with a much larger dotsize. These indeed show a reduced graininess without a changing the colors to drastically.

Current Limitations

At this moment the following effects are not modeled.

1) The effects of drops on each other if flight or during firing. It is not modeled that the drops influence each other in flight from nozzle to the paper.
2) The effects of drops on each other on the substrate. The spreading of ink over the substrate can be quite drastically influenced by other ink drops. It is expected that this will be very difficult to simulate.
3) There is no color management in the output. For instance magenta (ink) drops will be simulated by magenta ink. The dot gain can be simulated by adjusting the drop size, but the color of the magenta ink will be not identical to the real print. We are trying to simulate a system that has a Yule-Nielsen (high optical dot gain) characteristic with a system with a true Neugebaur characteristic (no optical dot gain). We only simulate the high optical dot gain by changing the dotsize, not the dot color.
4) The addition model for the drops assumes a linear addition behavior in densities. This is what is expected for layers of ink stacked upon each other, but this might not be the correct model for the effects of the optical dot gain.

References

1. Ming-Kai Tse, David J. Forrest, and John C. Briggs, “Automated Print quality analysis for Digital Printing Technologies,” PPIC/JS: The society of electrophotography of Japan, Pan-Pacific Conference/Japan Hardcopy ’98, July 15-17, 1988, Tokyo, Japan.

Biography

Peter Welten holds a degree in Chemical Engineering from the Technical University of Eindhoven (1986), The Netherlands. He started his career in Stork Digital Imaging BV (1986) in development of inks for electrographic colorproofers. After the electrophotography he worked on continuous flow inkjet inks, and later moving to the image quality and the color management of continuous flow inkjet inks, especially in textile printing.

Kees de Zeeuw holds a degree in Physics from the Technical University of Eindhoven (1985). The Netherlands. He started his career in Stork Digital Imaging BV (1992) in development of dither methods for continuous inkjet colorproofers. At this moment he is involved in color management, image processing and image quality for new and existing inkjet printers for proofing in the graphic arts industry.